SCIENCE

FRIDAY, JULY 28, 1899.

CONTENTS:

MSS. intended for publication and books, etc., intended for review should be sent to the responsible editor, Professor J. McKeen Cattell, Garrison-on-Hudson N. Y.

THE NICARAGUA CANAL ROUTE.

THE attention which the problem of connecting the Atlantic and Pacific Oceans by means of a ship canal is now attracting lends an interest to any information concerning the Isthmian region and affords an excuse for the publication in SCIENCE of matter more fully published in other less widely circulated media.*

Exact information concerning the Nicaragua Canal Route is derived chiefly from four surveys of the region, made with a view to determining the best route for a ship canal. The first was made by Colonel Childs, in the interest of the Vanderbilt Transit Company, which held a concession from the Nicaraguan government for constructing a canal. The second was made by Commander Lull, under instructions from the Secretary of the Navy. These two surveys amounted to a good reconnaissance and served to show that no insurmountable obstacles were to be met with. The third survey was that made by the Maritime Canal Company, under the direction of Chief Engineer A. G. Menocal. This extended over several years, and was much more comprehensive than either of the

* Physiography and Geology of region adjacent to the Nicaragua Canal Route. *Bul. Geol. Soc. Am.*, vol. 10, pp. 285-348. 1899.

Physiography of the Nicaragua Canal Route. *Nat. Geog. Mag.*, July, 1899.

Appendix 2, report of the Nicaragua Canal Commission, 1897-99. Govt. Print. In press.

others. It resulted in the location of a route and the formation of final plans, on which construction was begun. Financial difficulties brought the work to a stop, and a proposition to transfer the concession and property of the Company to the United States brought the matter before Congress. In order to obtain information on which to base its action, Congress provided for the appointment of a commission to determine the feasibility and cost of the undertaking. This commission, of which Colonel Ludlow was president, made no actual surveys, but examined the route selected by the Canal Company, and its surveys, plans and estimates. As a result of this examination the commission doubled the estimates of cost made by the Company, and suggested material modifications in the plans adopted. It recommended that further investigation of the route be made before final action was taken by Congress. In accordance with this recommendation a new commission was authorized and appointed in 1897. This commission, of which Rear Admiral Walker was president, employed a large corps of engineers and carried on active field operations throughout the greater part of 1898. The work was conducted under the immediate supervision of Chief Engineer E. S. Wheeler, to whom the excellence of the results obtained is largely due.

This fourth survey of the canal region has been made on a somewhat more comprehensive plan than any of the others, and, while former work has been utilized, every important point has been carefully verified. Special attention has been paid to two subjects, hydrography and geology, concerning which, as pointed out by the Ludlow commission, the available information was extremely meager. Mr. A. P. Davis and the writer were detailed from the Geological Survey to conduct the investigations on these subjects.

Mr. Davis established a large number of stations, at which the streams were gauged and the rainfall and evaporation measured. The importance of his observations and deductions is shown by the material modifications they have necessitated in the Canal Company's plans.

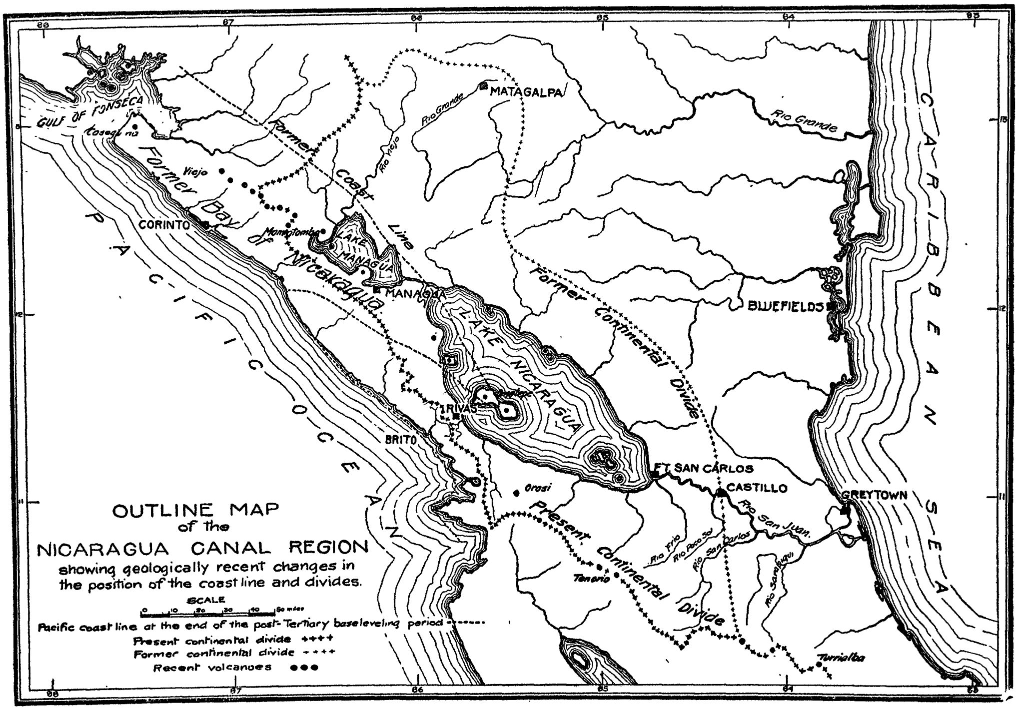
The geologic work consisted in a systematic examination of the region adjacent to the canal route and in an examination of sub-surface conditions by means of the drill. Ample facilities were afforded for the latter, and a mass of exact information was obtained as a basis for estimates by the engineers. Owing to the great depth of rock decay in this region and the extensive accumulations of alluvium, estimates both for foundations and for excavations made without the data furnished by the drill are open to serious question.

Until the investigations of the Walker commission the information obtained by the various surveys was such as comes strictly within the purview of the engineer, and many facts having the most direct bearing upon the canal problem were entirely overlooked or ignored.

Notwithstanding the large amount of work done by eminent engineers in this portion of Central America, its physiographic features have never been adequately described. As late as the report of the Ludlow commission the conventional Humboldtian view of the topography prevails. According to this view, which should be definitely discarded at the outset, a continuous mountain chain connects the Cordilleran system of western North America with the Andean system of western South America. Hill has fully demonstrated the falsity of this old view and shown the complete independence of the orographic systems of the three Americas.

The most striking physiographic feature in this portion of Central America, and the one which has the most direct practical

bearing on the location of a canal route, is the great depression which extends diagonally across the isthmus, holding the Lakes Managua and Nicaragua and their outlet the San Juan River. Its southwestern margin is formed by the lofty volcanic range of northern Costa Rica, while it is less definitely limited on the northeast by the Chontales hills, which extend from the Caribbean coast westward to the lakes. The *Nicaraguan Depression*, as above outlined, is not a simple river valley, although it is now occupied by a single trunk stream and its tributaries. Except for the constructional volcanic slopes at its southern margin, the depression is due entirely to ordinary stream erosion. During its formation, however, the continental divide occupied a position near the axis of the isthmus, while the western coast was indented by a deep bay reaching to the center of the present basin of Lake Nicaragua. The relations of present to former divides and coast lines are shown on the accompanying map.



Considering a broad belt extending across the isthmus and embracing the Nicaraguan depression, three distinct types of topography are encountered, viz.:

Old-land areas with maturely developed degradational surfaces.

Recent flood-plains and deltas with still-forming aggradational surfaces.

Recent volcanic cones and plateaus with slightly modified constructional surfaces.

The old-land occupies much the larger portion of the region represented on the accompanying map. It forms the greater part of the Nicaraguan depression and expands northward between the divergent lines of the Caribbean coast and the Nicaragua-Managua lake basins. It also forms the narrower part of the land strip between lake Nicaragua and the Pacific. This old-land surface appears to have been above

sea level since the middle of the Tertiary, and its form is due entirely to the action of subaerial gradational forces. Although composed largely of volcanic rocks, the original constructional surfaces appear to have been entirely obliterated.

When examined in detail the old-land surface is found to have considerable diversity in its relief, and its topographic forms naturally fall into three classes. These are (1) fairly well developed and subsequently dissected peneplains whose remnants rise gradually from either coast toward the axis of the isthmus, which until recent geologic times was occupied by the continental divide; (2) residual hills or monadnocks which rise distinctly above the peneplain surface, being most numerous toward the axis of the isthmus along the former continental divide, and (3) many valleys which intersect the peneplain surface, having been cut during a period of high level and subsequently somewhat depressed.

The peneplain was most extensively developed near the east coast, but it has here suffered most from subsequent erosion, and only a few remnants occur along the lower portion of the San Juan Valley. Higher up the valley, at a distance of 40 or 50 miles from the Caribbean coast, the peneplain was well developed, and, although deeply dissected, the even summits of the hills, about 150 feet above sea level, and considerable areas of level country back from the river, give evidence of its former extent. To the west of the former divide a corresponding peneplain is found sloping gently westward. It forms a plain of variable width about the lower portion of Lake Nicaragua and doubtless extends beneath the waters of the lake.

As indicated above, the residual hills are most numerous near the position formerly occupied by the continental divide, being separated by low colls, in which opposing streams headed, slightly above the level of the peneplain. The San Juan Valley, where it crosses this monadnock belt, is very narrow and bordered by high hills with serrate outlines totally unlike the low even-topped hills on either side. The monadnocks increase in height and numbers toward the north, forming the Chontales hills, which merge with the mountains of northern Nicaragua. The latter reach altitudes of 5,000 to 7,000 feet.

The valleys which intersect the surface of the peneplain were cut when the land stood at least 200 feet higher than now. They have a much steeper gradient than the present streams, showing that the high-level period was not long enough for the streams to reduce their channels to base-level. A subsequent depression of the land drowned the lower portions of the valleys. On the Pacific side, where the coast is bold and rugged, these drowned valleys are comparatively narrow and filled with alluvium nearly or quite out to the rocky headlands, but the alluvium never extends seaward beyond the latter to form a delta. On the Caribbean side the rivers are longer and deliver more sediment than the waves and littoral currents can dispose of, and hence have not only filled the estuaries formed in the drowned valleys, but have built out a series of deltas which coalesce and form a coastal plain. The sediment brought down to the sea by streams north of the San Juan is small compared with that brought down by those to the south. The more rapidly growing southern deltas would, therefore, be extended seaward except for a strong northward sand current set up by the oblique direction at which the waves strike the shore. This sand current tends to distribute the sediment evenly along the coast and preserve gently curving coast lines. Sediment, however, is delivered by the San Juan slightly faster than it can be distributed. Hence it tends to build out a delta, but this is deflected to the northward and forms a curved sandspit which for a

time makes a sheltered harbor. As the sandspit continues to grow, its point eventually joins the mainland, and the harbor is converted into a closed lagoon. This complete cycle of changes has taken place at Greytown during the last century and a half, as shown by the early maps of that portion of the coast. The cycle has also been repeated at the same point several times previous to the one of which there is documentary evidence, giving rise to the several distinct lagoons which occur inland from the one last formed.

The surface of the San Juan delta-plain is diversified by occasional hills which were at one time islands fringing the coast, and also by numerous lakes and lagoons due to the uneven distribution of the sediment. At its inner margin it abuts against the foothills or merges with the broad flood-plain of the river.

The San Juan leaves the lake practically clear, and most of the sediment which it delivers at its mouth is received from two large southern tributaries, the San Carlos and the Sarapiqui. These have their source upon the slopes of the Costa Rican volcanoes, and bring down vast quantities of black volcanic sand. Below the mouth of the San Carlos the trunk stream carries more and coarser sediment than any of the smaller tributaries. It has, therefore, built up its flood-plain more rapidly than the tributaries, and the latter are dammed, forming extensive lagoons in the side valleys.

The recent volcanic activity in this region has given rise to two series of vents, having a very striking linear arrangement. The southern series extends diagonally across the isthmus, in northern Costa Rica, terminating near the Pacific in the extinct volcano Orosi. The materials extruded from these vents have built up the massive mountain range which forms the southern border of the Nicaraguan depression. The second series of vents extends northwestward from Madera, on an island in Lake Nicaragua, to Coseguina, on the Gulf of Fonseca. Between Madera and Orosi, the proximate ends of the two lines, is a gap of about 30 miles. The northern vents were at first submarine, extending in a line nearly parallel with the former coast. They have built up a broad, gently-sloping plateau, from which rise, singly and in groups, many symmetrical volcanic cones. Most of these vents are extinct, while a few have been in eruption since the Spanish conquest, but are now quiescent. The older cones have suffered considerable modification by erosion, while the newer ones, and also the plateaus, retain, in a large measure, their original constructional forms.

The rocks of the Nicaraguan depression are, so far as known, Tertiary and later. They include both sedimentary and igneous formations, though the latter greatly predominate. The strip of land between Lake Nicaragua and the Pacific, southward from a point opposite the Island Zapetero, is composed chiefly of sandstone and shales, with some beds of limestone, which Dr. Dall pronounces to be of Tertiary (Oligocene) age. The sandstones contain a large proportion of volcanic matter and might almost be classed as andesitic tuffs. Another area of similar rocks crosses the San Juan Valley between Castillo and the Boca San Carlos, and may originally have been continuous with the area west of the lake. With the exception of this small area of sandstone, the entire San Juan Valley is composed of igneous rocks, including lavas, tuffs, breccias and conglomerates. These are all, so far as known, of Tertiary age. The lavas are chiefly basalts, andesites and dacite. The recent volcanic rocks are chiefly andesites, with a few lava flows of basalt.

The climatic conditions prevailing in this region have a very direct connection with its physiography and form one of the most

important factors in the canal problem. Through the greater part of the year the trade winds prevail with fairly constant direction and force. They are deflected slightly to the north by the high volcanic range of Costa Rica and to the south by the mountains of northern Nicaragua. The low gap across the isthmus constituting the Nicaraguan depression thus receives more wind than would be due to the normal trades, and it is probably this congestion of the air currents that causes the exceptional precipitation of this region. Within the zone of maximum precipitation which embraces the coastal plain and adjacent hills, forming a belt from 50 to 75 miles broad, the annual rainfall reaches nearly 300 inches. Beyond this belt, with increasing distance from the Caribbean coast, it decreases very rapidly, and in the western portion of the region the average annual rainfall is less than a third and in some seasons less than a tenth of that on the eastern coast. More important, however, than the absolute amount of rain is its distribution throughout the year. In the eastern division the rain is distributed with tolerable uniformity through the year. In the western division, on the other hand, there is a distinct dry season of five or six months. These climatic differences give rise directly to very striking differences in vegetation and, either directly or indirectly, to differences in the appearance and structure of the soils, in the topographic forms of the land surface and in the effectiveness of various physiographic processes.

The eastern division is covered by a dense tropical forest wherever the land is sufficiently firm to support large trees. The falling rain is intercepted by the canopy of foliage and filters gradually down to the surface, where the smaller vegetation affords a further protection, so that the soil never receives the direct impact of the rain drops. The abundant forest litter decays rapidly, furnishing a constant supply of the complex organic acids which are chiefly instrumental in promoting rock decay, and the latter process is extremely active. Solid rock is rarely found, except in residual bowlders, at depths less than 40 to 100 feet from the surface. The prevailing soil is a very tenacious, residual, red clay which never becomes dry enough to be intersected by shrinkage cracks and which, although to some extent loosened by roots and insects, resists erosion to a remarkable degree. After a careful study of the region it was concluded that the absence of frost and the presence of the tropical forest more than counterbalance the enormous rainfall and that surface degradation is, on the whole, slower than in most temperate regions.

The western division, particularly that portion lying between the lakes and the Pacific, is characterized by open savannahs and the thin foliaged, thorny forests of a semi-arid region. The forest litter is mostly destroyed by fires during the dry season, so that rock decay is hindered and the soil is wholly unprotected from the torrential rainfall which inaugurates the wet season. The soil, which is never red, but generally dark blue, is alternately intersected by shrinkage cracks and saturated with water, a process which serves to loosen it almost as effectually as frost. It results that the streams, which are alternately rivulets and torrents, bear great quantities of detritus, and the surface degradation is comparatively rapid.

No sedimentary or other records have been found in this portion of Central America which carry its history back to an earlier period than the Tertiary. During the Oligocene there was probably free communication between the waters of the Atlantic and Pacific, the region of the Nicaraguan depression being occupied by a shallow sea in the vicinity of which were many active volcanoes. The extrusion of volcanic materials and the deposition of sediments

continued until late Tertiary time, when the region was elevated, a land barrier cutting off connection between the two oceans, which has never been restored. After a long period of quiesence, during which extensive peneplains were developed on both sides of the continental divide then occupying the axis of the isthmus, the region suffered another elevation and the peneplains were deeply trenched by river valleys. This period of gorge cutting was followed by a subsidence equal to about half the previous uplift. The river valleys were drowned, and the estuaries thus formed have since been in part or entirely silted up.

The renewal of volcanic activity in late Tertiary or post-Tertiary time gave rise to the two mountain ranges above described. The position of the northern series of vents with reference to the coast line was such that when their ejected material had reached the surface of the sea it formed a barrier across the bay which then indented the Pacific coast. This barrier was built gradually higher by successive eruptions, and since in the area behind it precipitation was greater than evaporation the waters rose above sea level and doubtless escaped westward over the barrier during periods of quiesence in the volcanic activity. As the surface of the barrier was raised by the addition of volcanic ejecta, the surface of the impounded waters was raised to a height probably somewhat above the present elevation of Lake Nicaragua. The lake thus formed occupied not only the position of the former bay, but flooded the basins of the tributary streams and was considerably larger than the present Lakes Managua and Nicaragua combined. Its surface finally reached a low point in the continental divide where a west-flowing stream headed against one which occupied the present position of the San Juan. When this point was reached the intermittent escape of the impounded waters across the volcanic dam to the westward was changed for a permanent outlet to the eastward.

The gap when first discovered and overtopped by the rising waters was doubtless in deeply weathered rock and residual clay. It must, therefore, have been cut down very rapidly until the underlying hard rock was reached, when the permanent level of the lake was established which it has retained practically unchanged to the present time. It is quite possible that the gaps through the continental divide to the east and through the divide between the lake and ocean to the west were so near the same level that the impounded waters had for a short time an outlet both to the Atlantic and to the Pacific. The upper Rio Grande is flowing in a partly silted-up rock gorge much too large for the present stream, and it appears probable that this gorge was cut by the outflow from the lake before it was entirely and permanently diverted to the eastward outlet.

Certain features which have a specially direct bearing upon the canal problem should receive a further word of description. One of these is the gap followed by the canal route between the lake and the Pacific, the lowest gap in the continental divide between the Arctic Ocean and the Straits of Magellan.

The lower portion of the lake is bordered by the peneplain above described which, in the vicinity of Rivas, is very perfectly baseleveled. The plain rises gradually westward from the lake shore to the range of hills which forms the divide. These hills are from 500 to 1,200 feet high and extend northward to a point opposite the Island Zapetero where they meet the Jinotepe plateau and their residual old-land forms give place to the even constructional slopes of the latter. A single break occurs in this continuous line of hills, forming the gap between the waters of the Rio Lajas and the Rio

Grande, and whose summit is only 50 feet above the lake and 154 feet above sea level. This gap, which occupies so important a relation to the proposed canal, is the product of the familiar process of stream capture. Owing to the decided advantages possessed by the streams flowing directly to the Pacific over those flowing eastward, at first to the bay indenting the Pacific coast and afterwards to the lake, the former were able to cut backward through the divide into the drainage area of the latter and to divert their headwaters. In this way an eastward-flowing stream originally occupying the position of the Tola, the upper Rio Grande, the Guiscoyol and the Lajas was beheaded and the drainage of a large part of its basin was diverted to the Pacific. The deserted valley of this stream forms the low gap through which the canal route is located. It is so broad and level that accurate instrumental work is required to determine the actual summit of the continental divide.

Considering the origin of Lake Nicaragua, it is manifest that it must originally have extended entirely down to the point where its waters escaped through the gap in the continental divide—that is, to the present Castillo Rapids. This point, however, is now more than 30 miles down the San Juan River from the lake. The upper portion of that river meanders through an alluvial plain which becomes narrower down streams and has evidently been reclaimed from the waters of the lake by sedimentation. It is well recognized that lakes are ephemeral features, and the commonest way in which they are obliterated is by the filling at their upper ends with sediment deposited at the mouths of tributaries. In this case, however, the process is reversed. The area of the lake is being contracted chiefly by filling at its lower end. The filling is being accomplished by the tributaries entering this lower portion of the lake, many of which have been converted into tributaries of the San Juan. The present river channel does not coincide with the position of the river which formerly occupied this basin before it was drowned by the waters of the lake. Its position is dependent on the relative amounts of sediment delivered by the tributaries on either side, and it has been pushed toward the northern side of the old basin by the larger tributaries from the south, the Frio and Poco Sol. This portion of the San Juan may best be described as a *residual river channel*—that is, a broad arm of the lake has been gradually constricted by the deposition of sediment on its margin, and all that remains is the narrow river channel kept open by the current of water flowing from the lake. This hypothesis, verified by borings made in the river channel, has been of material service in so locating the canal line that all rock excavation in this portion between the lake and the Castillo Rapids should be avoided.

While the writer has no intention of touching upon the engineering features of the canal problem, it may be stated that the geologic examination of the route, including the boring, has resulted, in nearly every case, in showing that conditions are more favorable than they had previously been assumed. In the few cases in which less favorable conditions were found modifications in the plans suggested themselves by which the unfavorable conditions are avoided.

Thus the project, which has repeatedly been pronounced feasible by eminent engineers, is placed in a still stronger position by the most exacting scientific tests.

C. WILLARD HAYES.

U. S. GEOLOGICAL SURVEY, July, 1899.

---

*TRANSPARENCY AND OPACITY.**

ONE kind of opacity is due to absorption; but the lecture dealt rather with that de-

* Abstract of a lecture given by Lord Rayleigh before the Royal Institution of Great Britain.